Design of Prototype Supercritical CO_2 Superheater Heat Exchanger

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- A supercritical CO_2 (SCO_2) cycle has been emphasized as the next generation nuclear technologies because of its theoretical promise of efficiency, compactness, and moderator working temperature.
- The present study showed the design procedure of the superheater heat exchanger, such as heat exchanger selection, material selection, performance simulation, structural integrity evaluation, etc.

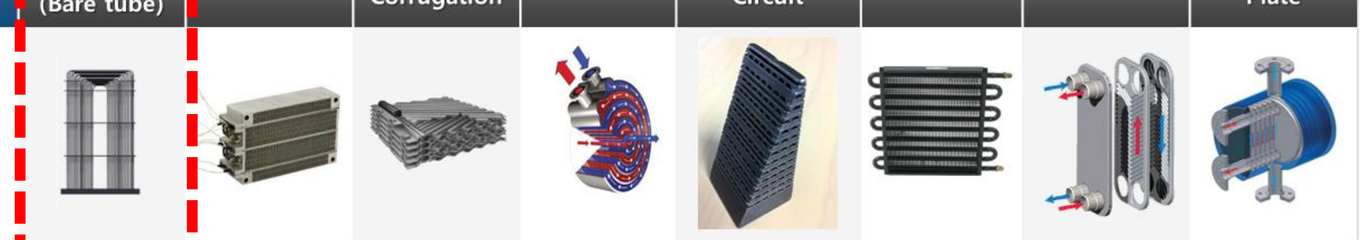
Table. Operating condition of superheater

Mass flow rate (kg/s)	1.00	Heat duty (kW)	370
SCO_2 T_{in} (°C)	300	SCO_2 T_{out} (°C)	600
SCO_2 Outlet P (bar)	200	ΔP constraint (bar)	< 1.45
Flue gas T_{in} (°C)	800	Flue gas property	LPG

✓ Heat exchanger type selection

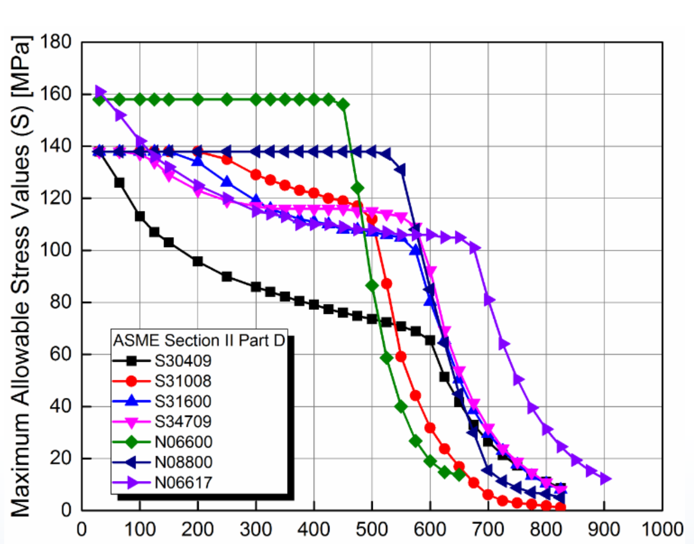
- Endure high pressure and high temperature
- Maintenance and inspection
- Tubular type as the superheater heat exchanger

Table. Various types of heat exchangers

	1. Tubular (Bare tube)	2. Plate Fin	3. Cross Corrugation	4. Spiral	5. Printed Circuit	6. Tube Fin	7. Plate	8. Shell and Plate
Geometry								
Maximum Pressure (bar)	200	100	10	30	300	200	30	30
Maximum Temperature (°C)	800	800	300	400	800	300	300	300
Effectiveness	~85	~90	~90	~90	~95	~85	~85	~90
Comments	High durability for high pressure and temperature conditions	High effectiveness High pressure drop	High effectiveness Limited for high pressure	High pressure drop of nozzle part	High manufacturing cost Relatively high weigh High pressure drop	Not suitable for air to air	High Effectiveness High pressure drop Limited for high pressure	High pressure drop

✓ Material selection

- Selection consideration: cost, properties, fabricability, and availability
- Major consideration: max. allowable stress ($T_{outer,surface}$ = 650°C)
- Max. allowable stress > 44.1 Mpa



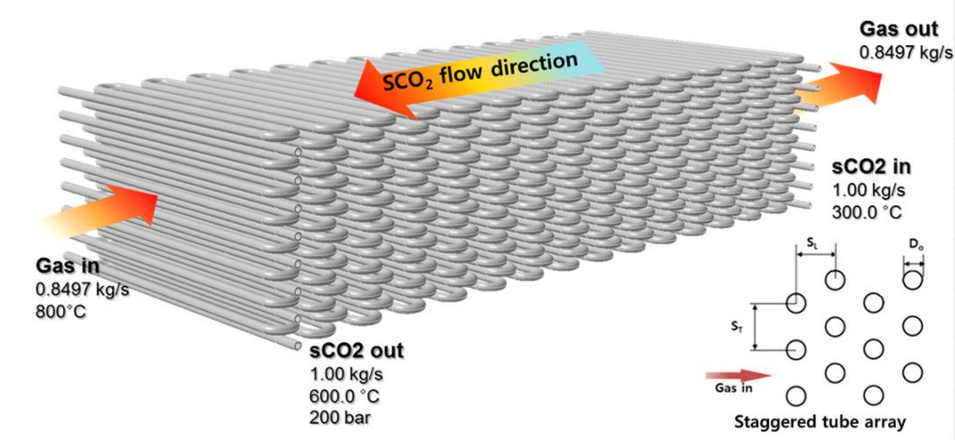
Material	S at 650°C	Remark
S31008	Impossible	High corrosion resistance
S34700	Possible	High corrosion resistance
N06600	Impossible	High corrosion resistance
S30400, S30409, S30451	Possible	Low corrosion resistance
S31600, S31609, S31651	Possible	Low corrosion resistance
S34709 (TP347H)	Possible	High corrosion resistance
N08800, N08810, N08811	Possible	Carbonization, Expensive
N06617	Possible	Expensive

Fig. Maximum allowable stress according to temperature and summary of various materials

- S34709 was finally considered.
- Allowable tube diameter and thickness = 21.7 mm & 4.9 mm

✓ Design of prototype superheater heat exchanger

- Staggered flow configuration & counter-cross flow
- Tube bending → ASME Sec. III



Tube type	S34709
Tube	Φ 21.7 x 4.9t
Length pitch (S_L)	35 mm
Height pitch (S_T)	60 mm
Tube Width	800 mm
Tube Height	471.7 mm
Tube Length	2086.7 mm
Tube volume	1.042 m^3
Tube weight	257 kg

Fig. SCO_2 heat exchanger specification

Superheater total length	5132 mm
Combustor length	1577 mm
Chamber (HX) length	2765 mm
Stack length	790 mm

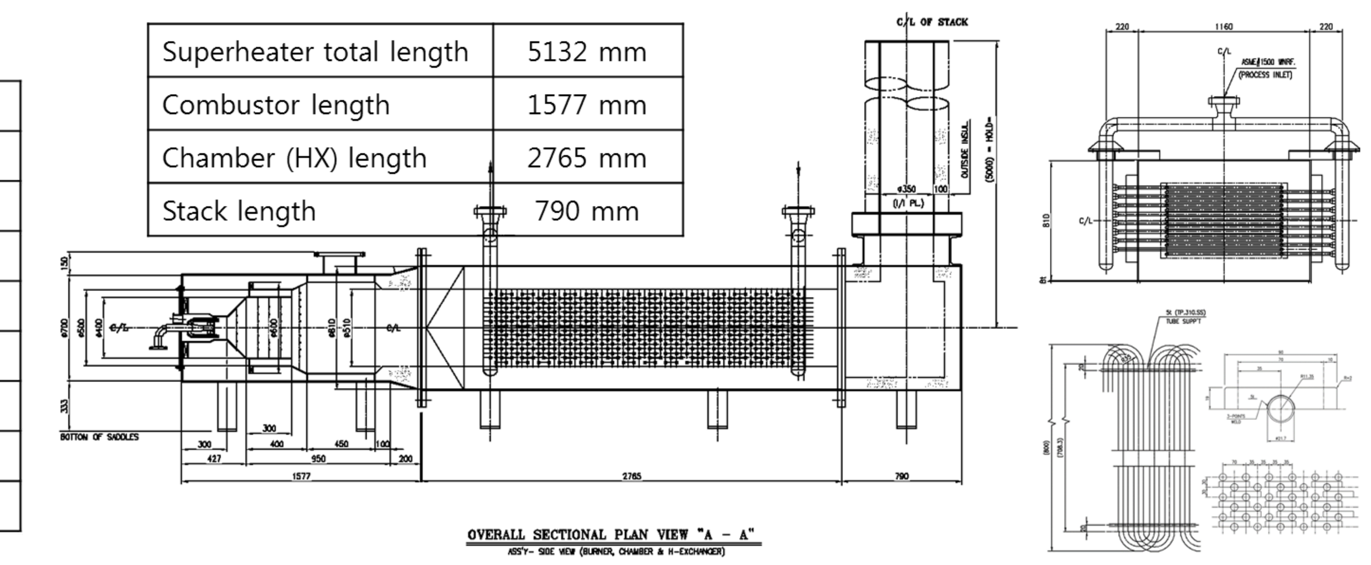
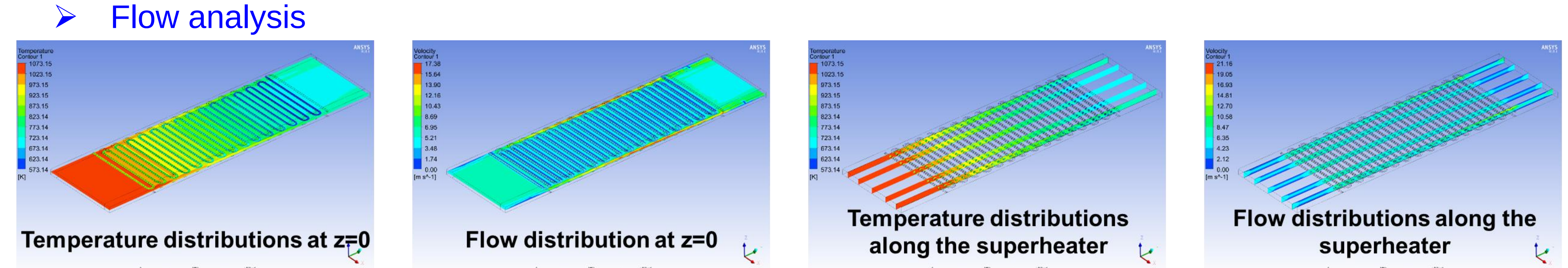


Fig. Preliminary design configuration of the superheater

✓ Performance simulation of the SCO_2 heat exchanger

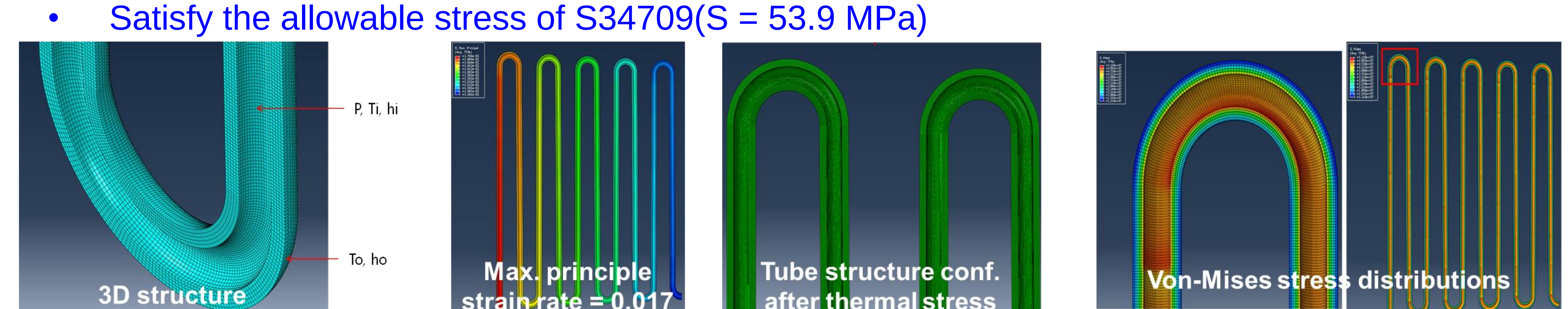
- Flow analysis



Mesh configuration							
Number of node		9,555,606		Number of element		10,698,900	
Turbulence		RNG k-e with radiation					
SCO_2 flow condition (center tube)							
Flow rate	0.0625 kg/s	T_{in}	300 °C	P_{out}	200 bar		
Flue gas condition							
Flow rate	0.1062 kg/s	T_{in}	800 °C	P_{out}	1 bar	Radiation effect	

SCO2 T_{in}	300 °C	SCO2 T_{out}	605 °C
Flue T_{in}	800 °C	Flue T_{out}	454 °C
SCO_2 △P	0.374 bar		

- Thermal stress analysis
  - (1) heat load, (2) pressure load, and (3) heat and pressure load
  - Satisfy the allowable stress of S34709(S = 53.9 MPa)



✓ The possibility of manufacturing process was verified by the tube supply, the structural safety analysis of the tube bending process according to the ASME Sec. III (Minimum thickness for pipe bends for induction and incrementing bending), and the thermal stress simulation at high temperature regions. Detail design of the superheater heat exchanger will be performed.